

Transcranial direct current stimulation to lateral prefrontal cortex could increase meta-awareness of mind wandering

In a recent article, Axelrod et al. (1) present the results of an intriguing transcranial direct current stimulation (tDCS) study, showing that noninvasive electrical stimulation of the dorsolateral and rostrolateral prefrontal cortex (PFC) increases the propensity to mind-wander. Further, they show that sham stimulation at these same PFC sites does not increase mind wandering, nor does veridical stimulation of the occipital cortex. Given the widespread tendency in cognitive neuroscience to focus attention largely or solely on the role of the default mode network in mind wandering, this study represents an important step toward a better appreciation of the roles of many other brain areas, especially lateral PFC. Furthermore, it offers the best evidence to date for a causal role for lateral PFC areas in mind wandering.

An intriguing question that emerges from this new dataset concerns how tDCS stimulation of lateral PFC might have affected meta-awareness of mind wandering. In addition to, or instead of, increasing the frequency of thought, this stimulation may also have altered participants' meta-awareness of those thoughts. Lateral PFC regions (particularly dorsolateral and rostrolateral PFC) have been shown in many studies to be critically involved in meta-awareness of internal states and mental content (2), and studies using paradigms similar to that of Axelrod et al. further support this connection. For instance, a recent study used theta-burst transcranial magnetic stimulation (TMS), which reversibly "lesions" a brain area by disrupting ac-

tivity. They found that applying TMS to dorsolateral PFC severely impaired meta-awareness (3). Another study from our group using real-time neurofeedback with functional magnetic resonance imaging trained subjects to voluntarily up-regulate activity in rostrolateral PFC. The success of the up-regulation correlated with enhanced meta-awareness of internal thought streams (4). Overall, this evidence strongly argues that external modulation of lateral PFC can have marked effects on meta-awareness.

Empirical research suggests that mind wandering frequently occurs below the level of conscious awareness: Having participants report when they catch themselves mind wandering results in far fewer reports than if they are caught instead by periodic probes from the experimenter (5). We all mind-wander unconsciously on a regular basis (e.g., while reading), and there are major interindividual differences in the capacity to notice that one's mind has wandered (5). The mind wandering that participants report in an experimental setting might merely represent that portion of thought that they become meta-aware of, either during the mind wandering itself or shortly thereafter (5). Although stimulation of lateral PFC might directly increase mind-wandering frequency, it might also simultaneously lead to enhanced meta-awareness of this mind wandering. The combination of both effects could lead to the observed increase in both subjectively experienced and experimentally reported task-unrelated thought.

Despite the mounting functional neuroimaging evidence implicating lateral PFC in mind wandering, the correlational nature of neuroimaging limits our understanding of whether these areas are necessary or merely incidentally involved. The study by Axelrod et al. is an innovative and welcome step toward overcoming these limitations and expanding our knowledge of the causal link between PFC recruitment and the subjective experience of mind wandering.

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- 1 Axelrod V, Rees G, Lavidor M, Bar M (2015) Increasing propensity to mind-wander with transcranial direct current stimulation. *Proc Natl Acad Sci USA* 112(11):3314–3319.
- 2 Fleming SM, Dolan RJ (2012) The neural basis of metacognitive ability. *Philos Trans R Soc Lond B Biol Sci* 367(1594):1338–1349.
- 3 Rounis E, Maniscalco B, Rothwell JC, Passingham RE, Lau H (2010) Theta-burst transcranial magnetic stimulation to the prefrontal cortex impairs metacognitive visual awareness. *Cogn Neurosci* 1(3):165–175.
- 4 McCaig RG, Dixon M, Keramatian K, Liu I, Christoff K (2011) Improved modulation of rostrolateral prefrontal cortex using real-time fMRI training and meta-cognitive awareness. *Neuroimage* 55(3):1298–1305.
- 5 Schooler JW, et al. (2011) Meta-awareness, perceptual decoupling and the wandering mind. *Trends Cogn Sci* 15(7):319–326.

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